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Humanizing heat as a service: Cost, creature comforts and the diversity of smart heating practices in the United Kingdom

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ABSTRACT

Why do people heat their homes the way they do? What are the underlying patterns or justifications for their heating preferences and practices? In this study, using data from the Energy Systems Catapult's Living Laboratory, we present a novel conceptual framework that ties together insights from "lived experiences" research with "narratives and energy biographies." We synthesize from these approaches the notion of "energy phenomenology," which holds that heating practices will be mediated by individual identity, experiential preferences and needs, socio-material attachment, and lifestyle changes. In other words, the energy phenomenology framework demands that we understand the lived experiences, practices, and identities that intercede and shape smart heat services and consumption. Then, we test this framework with three sets of primary data—undirected diary studies and blogging, directed diary studies and blogging, and household interviews—involving 100 homes using smart heating controls across Birmingham (West Midlands), Bridgend (Wales), Manchester (Greater Manchester), and Newcastle (Northumberland) in the United Kingdom. We identify seven different phenomenological uses of smart heat—parental care, alleviating pain, fresh air, personal care, zoophilism (caring for pets, animals, and plants), social signaling, and structural fortification. Rather than merely germinating from rational choices based on available information about the likely costs and benefits of their behavior, smart heating—an essential tool for the decarbonisation of buildings, fossil energy, and electricity—is a phenomenological process. Policy and research efforts that fail to appreciate these dynamics risk capturing only a partial and incomplete picture of how and why people heat homes and domestic spaces. The outcome could be that these policies will fail to meet their objective of decarbonizing domestic heating and averting climate change.

1. Introduction

Global efforts at decarbonizing energy services, predominantly electricity and heat, have focused in recent years on how adoption patterns and transitions processes can be harnessed to create a new world of energy decentralization, efficiency, and prosuming [1–4]. For some, decentralized energy supply has even become part of agendas to promote "energy democracy," attempts at transforming energy systems so that they become lower carbon but also more pluralistic, community oriented, and civically engaged [5–7].

More recently, there has been an increased focus from both policymakers and researchers on the use of heat and how that sector, which accounts for 37% of the United Kingdom's (UK) greenhouse gas emissions, could be decarbonized [8] as we also move towards a more digitalized, and net zero [9], society. Dominant trends in policy interventions concerning the behavior and energy consumption of households and industrial consumers remains shaped by particular kinds of evidence [10,11]. For instance in the UK, policy evidence related to energy consumption in homes has moved away from the more traditional rational consumer choice theories towards a mixture of behavioral economics. These take a more individualistic approach, from measures such as "nudge" interventions aimed at initiating behavior change, to social practice theory, which argues that energy is relied on for everyday life tasks and practices [12]. Such policy evidence in turn reflects particular assumptions within the behavioral and social science communities about the meaningful factors that shape energy consumption [10]. These factors, however, are far from simple or easily captured in existing sociological and psychological models [13]. Instead, energy consumption behavior is often inseparable from the values, practices, and systemic infrastructures that constitute a shared reality; these processes, moreover, can create

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their own "entangled practices" that cannot be reduced to individual choice or even reflective, reflexive, or judicious use of energy services [14]. Energy services and consumption and use are thus constantly "negotiated" in everyday life [15].

In this study, we ask: Why do people heat their homes the way they do? What are the underlying patterns or justifications for their heating preferences and practices? To capture this socio-material complexity of energy practices and routines, this study draws from two separate approaches—lived experiences, and energy biographies—to examine via the concept of "energy phenomenology" how people use smart heating controls in the UK. Our original data for the application of this energy phenomenology framework is undirected diary studies and blogging, directed diary studies and blogging, and household interviews involving 100 homes with smart heating controls in the cities of Birmingham (West Midlands), Manchester (Greater Manchester) and Newcastle (Northumberland), and the town of Bridgend (Wales). Based on these data, we identify seven distinct, and at times heartfelt and even humorous, uses of heat, from practices of care and nurturing for children or those who are unwell, to keeping pets and plants sufficiently warm, to protecting buildings and maintaining hygiene. We then discuss these results through the themes of identity, a multicity of needs, attachment, and lifestyle changes before concluding.

2. Energy phenomenology: "Lived experiences" meet "energy biographies"

Before summarizing our research design and presenting our findings, this section introduces our conceptual framework. This framework rests on the two pillars of lived experiences and energy biographies.

2.1. Grappling with lived experiences

Lived experiences scholarship emerged initially in the fields of psychology and health to understand how people deal with pain and suffering, or respond to new medical treatments. It has since then expanded into overall sociological approach that seeks to study human action and behavior, as well as the subjective meaning given to life events [16]. The strength of a lived experiences approach lies in its ability to describe and perhaps even understand emotions and non-rational elements of behavior, not captured by many other modes of inquiry, including stated preference techniques [17]. It does not view experience solely as some objective phenomenon or a series of solvable problems, reducing experience to the "tyranny of reason," or offering an artificial appearance of order. Instead, the approach appreciates and acknowledges uncertainties, other ways of interpretation and elements beyond facts and reasoning.

Furthermore, a lived experience approach tries to better capture the individuality and the uniqueness of the individual, a celebration of diversity. The approach recognizes the "ethnographically particular" nature of each person, that every human being is different. It also recognizes that people can have multiple, even competing or contradictory practices, and the meanings they give to them. In simpler terms, the method gives one the insider's view, and it can reveal the different roles and identities among and even within individuals. It therefore offers a lens by which "experiential knowledge" can be gained about individuals and small groups [18].

For reasons such as these, the approach has been used, although sparingly, in the energy studies field to examine fuel poverty among vulnerable groups [19] or social housing tenants [20]. Other studies have used lived experiences to examine energy poverty in Nepal [21], Congolese cobalt miners [22], energy workers in mines in Wyoming [23,24], the lived experiences of thermostats [25,26], and how people experience the impacts of climate change [27]. No study to our knowledge has yet applied it to smart heating controls.

2.2. Elucidating energy narratives and biographies

Work on "energy biographies" emerges out of the fields of sociology (social practice theory), lifecourse stages (demographics), geography (sense of place), and narratives (communication studies). It explores how people utilize energy biographies or stories to make sense of energy technologies, services, practices, and patterns. A narrative here is loosely meant to reveal a story an individual tells with a series of events ([28]: 13).

Henwood et al. [[10]: 2] write that the energy biographies methodology "recognizes that what people do and how they understand themselves are multiply conditioned," and "can reveal how the ways in which energy is used are not simply functional, but also shape our sense of identity and of what constitutes a 'worthwhile life'." Energy biographies research seeks to make visible the confluence of social networks, external conditions, and material infrastructures that shape people's lives and thus energy consumption profiles. Energy consumption becomes historically contingent, embedded in shared practices, and reflected in a diverse range of household and community contexts, revealing the "time and texture" of human action [29]. In simpler terms, the energy biographies approach seeks to unpack and explore the "everyday lives" of energy transitions [30,31]. It aspires to study how everyday energy use reflects the ways in which people make their daily lives meaningful [11].

Examining household energy use with the energy biographies approach is best suited to reveal people's investments in maintaining what they perceive as the normality of their everyday life [10]. As Henwood et al. [[10]: 8] add, the approach "allows researchers to explore people's practical and emotional investments in the taken-for-granted activities on which everyday life depends and which shape its textures." Moreover, the approach identifies moments or routines that households may take for granted but that can be reconsidered, disrupted or questioned [11,32,33]. According to this approach, energy users are conceived in multiple ways as:

- Participants or conduits for shared practices over which they have direct influence;
- Members of multiple communities of place or practice for whom shared visions or agency can become specified over time;
- Subjects of biographies by which life changes and shifts in lifestyle become apparent.

Narratives, stories, and biographies are thus seen as a salient way of visualizing energy systems and practices [34], making sense of past actions and decisions [35], as well as imagining energy transitions and desirable energy futures [36,37,38].

2.3. Introducing energy phenomenology

Essentially, the lived experience approach centers on the uncertainty and complexity of how specific individuals will experience—or even utilize or comprehend—the consumption of energy or heat. It also reveals how experiential knowledge, including emotions and routines, can shape energy consumption patterns. Conversely, the energy biographies approach brings to light the historical contingency of people's practices, as they are embedded in habits and technological systems, as well as how identity and collective values or norms will influence people. It moreover situates energy consumption within its material context, and within a particular moment in time, or cycle of a person's life [39,40].

Synthesizing from both approaches, Fig. 1 presents our "energy phenomenology" framework, which we understand as the lived experiences, practices, and identities that mediate and shape energy services and consumption. This approach holds that *individual identity,* whether one identifies as an environmentalist or consumerist, a parent or a child, someone wealthy or poor, will influence energy consumption. *Experiential preferences and needs* for things like a warm home, a clean bathroom, a comfortable living room, or a convenient way of doing a chore will

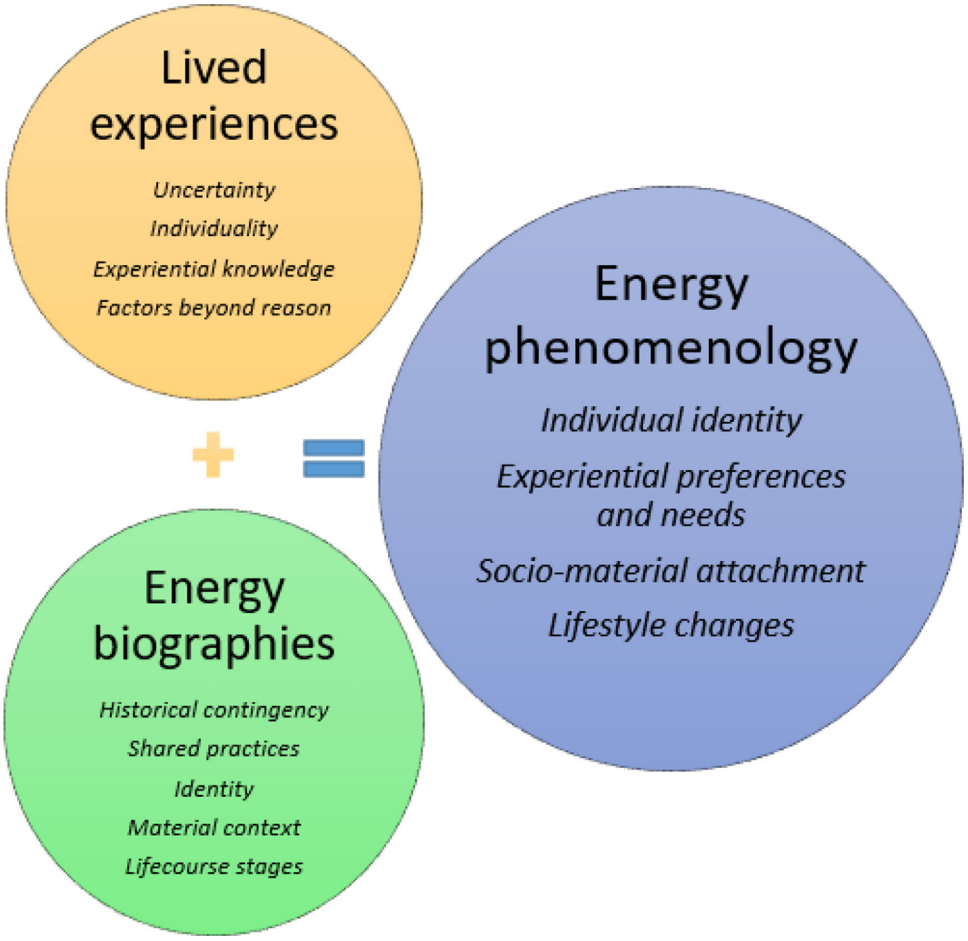

Fig. 1. An energy phenomenology approach to lived experiences and energy biographies. Source: Authors.

shape consumption. Historically shared practices, routines, habits, and norms can fuse together with infrastructure such as appliances, gas boilers, or buildings to lead to *socio-material attachment*. Heat practices are also dynamic and temporally complex, altering and changing across life events and stages, a process we term *lifestyle changes*.

We term this framework "energy phenomenology" because it situates energy or heating use at the nexus of emotion, cognition, and lived experience, which means it also conceptually sits between or across ontology and epistemology, or metaphysics and physics. Within philosophy, this is often called "interpretive phenomenology" [41]. Edmund Husserl is frequently credited as the founder of modern phenomenology, conceived as a way of doing modern philosophy that envisions reality as being constituted by phenomena—objects and events that are perceived in the human mind, and not of anything independent of human consciousness [42]. More colloquially, phenomenology is often seen as a way of returning philosophical inquiry to, and exploring the reality of, life and living through the study of the "life-world" or "lived experience" as it occurs "pre-reflectively" [43]. Our framework offers a way of describing events—or in this case, energy or heating phenomena—as they appear to the person experiencing them. Finlay [44] states that the special contribution and strength of phenomenology is the way it can capture the richness, poignancy, resonance and ambiguity of lived experience, allowing researchers to see the worlds of others in new and deeper ways. The approach can capture the path dependence of histories. For instance, if a person grew up with a tradition of drying towels on bannisters rather than a toweling rail, or having a Sunday lunch, then they may continue or rebel against these. Families may recreate patterns they grew up with, which then shape energy consumption. It is precisely these aspects of phenomenology that convinced us to describe it as our framework.

3. Research methods: qualitative data from a Living Laboratory

This section introduces our "Living Laboratory" research design as well as our methods of data collection, data analysis, and limitations.

3.1. The Energy Systems Catapult "Living Laboratory"

With our conceptual framework elaborated, our empirical research draws from an ongoing Living Laboratory. A Living Laboratory, or "living lab," is a social experiment where users have a central role in testing particular technologies, solutions, ideas or policies in a real-world or real-time environment [45]. JPI Urban Europe [[46]: 3] has defined a Living Lab as:

> A forum for innovation, applied to the development of new products, systems, services, and processes, employing working methods to integrate people into the entire development process as users and co-creators, to explore, examine, experiment, test and evaluate new ideas, scenarios, processes, systems, concepts and creative solutions in complex and real contexts.

Voytenko et al. [47] argue that for an experiment to be considered a living lab, it must satisfy the following key features: 1) be at a local or small scale, reflecting challenges at a more discrete level of management; 2) be experimental or quasi-experimental, having different groups

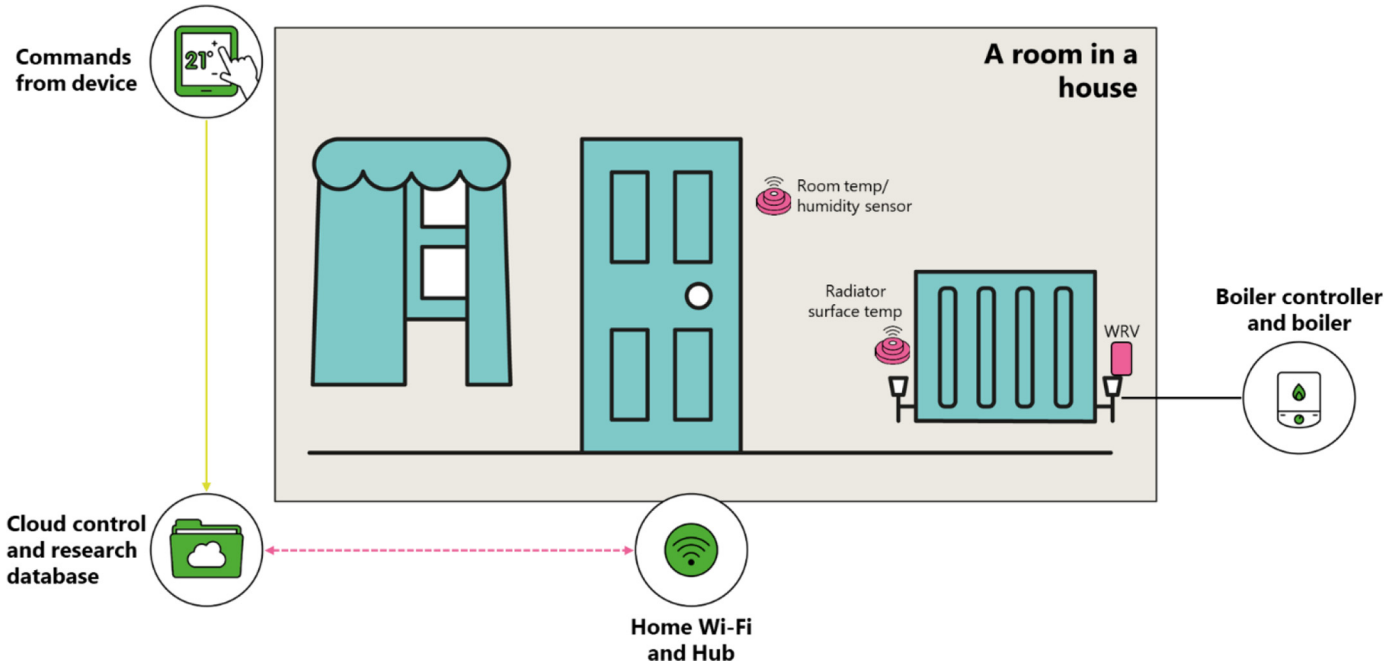

Fig. 2. Heat controls, applications, and scheduling available in the Living Lab.
Source: Authors, based on Living Laboratory data.

of participants; and 3) be participatory with direct user involvement. Living labs can therefore be used as a methodological tool for transforming users, or energy consumers, from observed subjects or end clients to co-creators of the research process. They also enable the study of users in their complex real-life context [48]–making them well suited to our energy phenomenology approach.

Our study utilizes primary data from the Energy Systems Catapult (ESC) Living Laboratory in the United Kingdom [49]. This Living Lab consists of 100 homes spread across four locations—Birmingham (West Midlands), Bridgend (Wales), Manchester (Greater Manchester), and Newcastle (Northumberland). All households were provided with "smart heat" systems that involved the installation of smart heating components and included zonal heating controls that could be controlled from smart phones or web browsers (see Fig. 2).

These smart heating controls and room sensors, which are connected to a cloud-based digital platform, enable households to monitor and control their heating needs in individual rooms, giving more accurate feedback of how heating is used throughout the house. Smarter control has the potential to improve heating practices in various ways. First participants found it easier to adjust the temperature in each room than adjusting the number on thermostatic radiator valves that were often hard to access, difficult to adjust and complicated to understand. They found it simpler to choose a target air temperature, than to know which number to set their valve to. Second, this improved accessibility enabled participants to more finely tune their heating to meet their needs, for instance turning heat down in rooms that they were not using, or enabling residents who preferred different temperatures to sit comfortably in different parts of the home. Finally, smarter control could give residents control over other aspects of their heating. For instance, participants were able to make their radiators warm for periods of time to dry laundry or to provide radiant heat, rather than heat the air to a specific temperature.

3.2. Recruitment and demographics

The specific Living Lab we draw our data from is made up of 100 households located in the four areas of England and Wales (see Table 1). All current participants were first contacted via email and then screened via telephone and booked in for a home survey to ensure their home is compatible with having the controls fitted. The demographics of the 100 Living Lab homes are also shown in Table 1.

3.3. Data collection methods

The aim of the Living Lab was to understand participant attitudes and behaviors when heating their home in order to help innovators design products and services of possible utility for a range of household types and sizes. Throughout the Living Lab, households had their homes surveyed and monitored, and they took part in a range of consumer research studies. As Table 2 reveals, these included research visits complimented by an extensive array of repeated data collection instruments, providing both qualitative data on the participant's experience of having the controls in their homes and their interactions when heating their home, and quantitative data on temperature, humidity and energy consumption.

For this particular paper, three sets of primary qualitative data from the Living Laboratory were utilized to document the lived experiences of heat: (1) telephone household interviews, (2) undirected diary studies and blogging along with directed diary studies and blogging, and (3) at-home in person household interviews.

First, *telephone interviews* were carried out during the pre-installation phase of the controls and for reviewing heating service designs. These telephone interviews enabled the researchers to disseminate complex information and gather qualitative feedback from participants. The semi-structured calls provided participants with the opportunity to raise ad hoc comments and share their questions and experiences with the researchers. These interviews lasted approximately 60 min, with all homes involved in a pre-installation call and 42 participants taking part in a call reviewing tailored options of a heating service.

Second, *blogs* were used to record household experiences of having the controls in their homes and their interactions when heating their home. Indeemo, a mobile ethnography app, was used to set participants ongoing research blogging tasks. The tasks set on the blog included: regular video tasks capturing changes made to heating schedules

Table 1
Composition and demographics of the 100 homes in the Energy Systems Catapult Living Lab.

Location

- West Midlands: 26
- Manchester: 5
- Bridgend: 32
- Newcastle: 37

Age of lead participant

- 18–34: 8%
- 35–44: 30%
- 45–54: 31%
- 55–74: 28%
- Unknown: 3%

Household type

- Family with adult children: 10%
- Family with children: 50%
- Cohabiting couple: 24%
- Adults cohabitating: 2%
- Single adult: 11%
- Mixed generations: 3%

Types of homes	*Age of homes*	*No. of bedrooms*
Bungalow: 3%	Pre-1945: 38%	1 bedroom: 1%
Mid-terrace: 13%	1945–1980: 33%	2 bedrooms: 16%
End-terrace: 5%	Post 1980: 26%	3 bedrooms: 46%
Semi-detached: 52%	Unknown: 3%	4 bedrooms: 28%
Detached: 24%	5 bedrooms: 9%	
Ground floor flat: 2%		
Unknown: 1%		

Source: Authors, based on Living Laboratory data.

Table 2
Technical measures and data collection techniques used in the Living Laboratory.

Technical measures installed	Data collection measures*
• A "hub" which operates on its own internal wireless network, or z-wave; • Wireless radiator valves; • Individual room humidity sensors; • Individual room temperature sensors; • Individual radiator sensors; • Central boiler controller; • Utility flow meters; • Water pipe sensors; • Repeater to boost the signal from the hub to devices around the home; • Batteries.	• A pre-installation telephone interview; • Undirected diary studies and blogging, done in written and video forms; • Directed diary studies and blogging, done in written and video forms; • Semi-structured in home/telephone interviews; • Standardized surveys to cluster outlooks, behaviors and motivations of the entire group; • Measurements of temperature and humidity in each room and radiator; • Measurement of gas and electricity consumption; • Measurement of user interaction with their heating controls.

Source: Authors.
* Note that this paper only reports on qualitative data collected at the Living Lab.

and the reasons for changes; feedback on the cost feature on the controls; reviewing their experience on the trial and feedback on heating service designs. The blog allowed the researchers to capture feedback from most of the homes in the Living Lab, with 75 signing up to the blog and providing updates during the trial. As the blogging tool provided live screen recordings of the changes made by participants, the researchers were able to see the users interface as well as reasons for changes. This feature provides information that is not as easily captured in written posts or home visits. Given some respondents treated their blogs as a diary, we sometimes use both terms when describing this data source.

Third, *at-home interviews* were conducted with a sub-sample of Living Lab participants to provide a deeper understanding into participant perceptions of "comfort" in their own homes and what an ideal low carbon alternative system or service would look like. Almost a quarter of homes (26 participants) each took part in a 90-min home interview. These interviews were used to understand the captured sensor data relating to the temperatures, spaces and times participants heated their home.

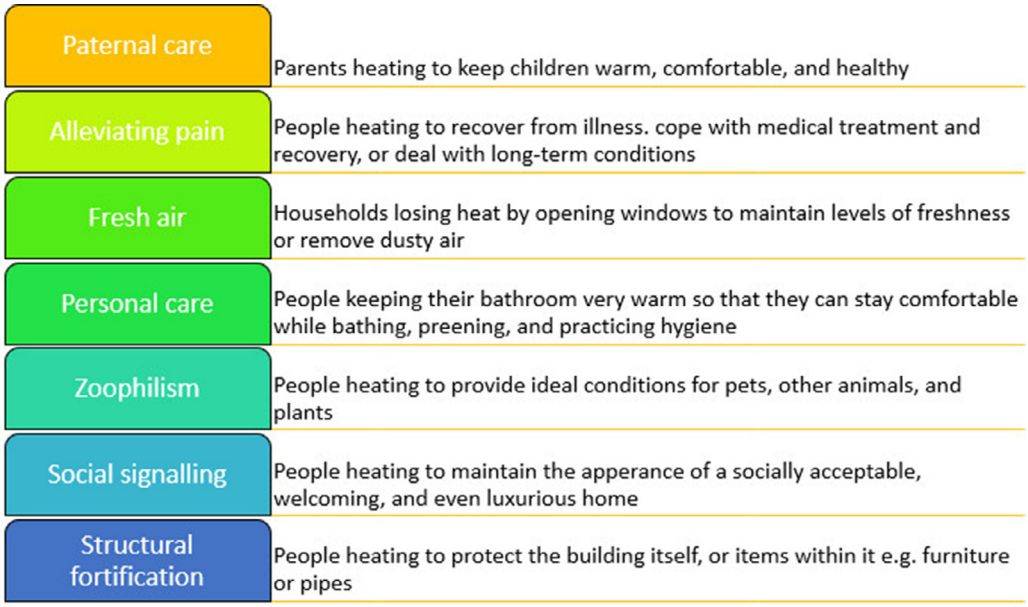

Fig. 3. The seven phenomenological uses of smart heating controls and diversity of heating practices.
Source: Authors.

3.4. Data analysis

Perhaps obviously, the data collected via the blogs/diaries and interviews was not explicitly focused on the lived experiences of heat, but instead the day-to-day workings of the homes in the Living Lab and the overall preferences, practices, and satisfaction levels of respondents. All in all, the research methods resulted in transcripts with thousands of comments and statements across hundreds of pages of text. Our goal in this paper was to extract from this deep dataset a focused look on differences in lived experiences.

To do so, the research team thematically searched the transcripts of the interviews and blogs/diaries for particular lived experiences that kept recurring, and then developed an inductive list of "phenomenological uses" of heat that we developed iteratively, and co-creatively, with the material. This recursive relationship between material and analytical categories has a strong element of "grounded" theory and research design [50,51]. Although the examples we selected show us varying types of uses of heat, they do reflect a small number of total examples or comments, which numbered in the thousands of pages of interview and blog/diary text. Indeed, data for this paper was collected from just under 1700 blog posts, 26 home interview transcripts (made up of approximately 10,000–15,000 words each), and 42 consultation call transcripts (ranging from approximately 4000–8000 words each). We have also taken examples from different homes, so that no single home or respondent is overrepresented in our results.

3.5. Limitations

Although we trust the study's results in terms of accuracy and completeness, our approach does have a number of notable limitations. The 100 Living Lab homes are not representative of the UK population, as the study did not include homes in fuel poverty or social housing blocks for example, consigning respondents to the middle and upper class categories in terms of income. Further, involvement in the Living Lab was geographically constrained, having to be located in one of the four areas of Birmingham, Bridgend, Manchester, and Newcastle.

Additionally, respondents were not asked directly about their lived experiences, they were not prompted to discuss them which means all of our results and examples emerged organically or naturally from the Living Lab data analysis. This means they had to be inferred inductively by the research team, rather than directly queried at, or solicited from, respondents. As a plus, this means our examples were not prompted, they occurred without intervention on behalf of the research team. However, their rather spontaneous nature makes it difficult to perhaps generalize them beyond a subsample of households.

Moreover, we did not make an attempt to correct, normalize, or weight the statements from participants, and instead treat all responses as valid and of equal merit. Finally, although the lived experiences of heating identified by the study emerged from a Living Lab with smart heating controls, it may very well be that many of them exist generally for heat—regardless of whether it is from smart controls or not. In other words, we never collected data from "normal" or "non-smart" homes which make it impossible to test whether our lived experiences hold true in those types of buildings.

4. Results: seven phenomenological uses of smart heating controls in the United Kingdom

A multitude of distinct heating uses or practices emerged from our data, which we classified inductively across seven different themes summarized in Fig. 3.

4.1. Parental care: heating for children

The first distinct theme concerns parental care, and the myriad ways that mothers and fathers (but also aunts, uncles, grandparents, and caretakers) utilize heat to take care of their children, keeping them warm, minimizing disease such as asthma, and maximizing comfort.

For example, one household noted in an interview that:

> I really only turn the temperature up when children tell me they're cold. Now, my son doesn't even have to tell me he's cold, but if it was the case where he would say, 'Dad, I'm cold,' then, you know, no fail, the heating would be on. When he is just in a vest and running around in his pants or whatever, then I put the heat to stop him feeling a chill.

Another stated that they use the heat to warm the pajamas for their son, noting that:

I used to like it when I was little, so I have passed it along to him. Sometimes he whines, and says, 'It's too hot, it's too hot,' but it's better than having a cold pair of pajamas, isn't it, really?

A third household commented that:

If it's cold in the mornings, I will turn the heating up for the little one, my son's two years old. We go gallivanting with him on the weekends, so I just go on my phone and turn my heating up if it's cold, which is great, because I can turn the heating up when I'm coming back home, from the car.

And a grandparent remarked that:

If I don't keep the house warm, the kids would turn around and say, 'The penguins are coming out, Gran.' It has been too cold, so I've even got an oil heater up there, in the bedroom, just in case it's cold for them, you know?

One parent even remarked that while they would not turn the heat up for themselves, they definitely would for their children, noting that:

I turn the heating up so it is warm when I arrive home from work … For the kids to come home, it's more important. Yes, that is important, to make sure everyone's comfortable.

Others discussed the need to maintain heating levels as a hedge against misbehaving and naughty children. In the words of one parent:

I have had to compromise my heating plan for my children. We have to just leave the heating on for a while, anyway, because it was just too cold for the kids. Our kids are, like, eight and five. So, in the morning when they were coming downstairs to eat their breakfast and they'd get changed. They'd change downstairs because they're naughty. So, you know, I don't want it to be freezing cold for them, so, yes, when it was December, January. February even, wasn't it? You know we'd have it on downstairs for a couple of hours to make sure that they're not freezing cold.

A final household wrote in their interactive blog that they need to maintain "warm mornings" to keep their children healthy. As they commented:

So we are in to our third week [with the Living Lab] now and I feel we are settling in to some sort of routine. It is nice to know that the heating will be on when I get up, instead of having to scuttle to the kitchen, frozen, to put the heating on. It is especially nice to be able to put the heating on for them remotely when they are feeling ill or about to get sick.

The parental care theme shows how parents, and grandparents alike, prioritize the needs of their children, or grandchildren, first when it comes to heating their homes. In noting these uses of heat, participants may also have been seeking to signal their status as a "good" parent according to some view they held of what "good" parenting might involve.

4.2. Alleviating pain: heating for health

The second theme centers on health, and how warm homes can prevent people from falling sick, and help those who are recovering from illnesses or who need to manage ongoing, long-term, health conditions.

As one household member confided in their blog, they need heat to manage painful arthritis.

I am not surprised at the category I am in terms of having a high consumption profile, as myself and my partner both have arthritis and we have to be comfortable with the heat in the house. I would not change my heating schedule as both myself and my partner need it be comfortable.

Another household respondent mentioned during an interview the need for warmth to recover from cancer.

I am very sensitive to feeling cold temperatures. Well, I was diagnosed with cancer in 2011, and that's how I retired. I gave up work. After having cancer, I feel the cold something terrible … I was in remission until January when they found a little lump on my kidney. I've had a scan two weeks ago and I go and see my oncologist on Wednesday, and if it's grown, it'll probably be chemo again… that means I really feel the cold. That's why I tend to have the heating on all the time.

One household mentioned in their blog needing warmth to help care for an ill family member:

I had a terminally ill relative here and found the system invaluable as I could dictate single rooms to heat at any time of the day or night without affecting others. This year I have responsibility sometimes with little notice for 2 young children at separate times. To be able to bring on heating in specific rooms from my mobile is so convenient.

Another household articulated needing heat to help their partner recover from a heart attack:

My husband is only home during the weekend or else my heating bill would be massive. He had a heart attack a few years ago so he is on blood thinning meds so he is always freezing cold, he wears thermals even in the summer. He wants the heating on all the time, so it comes down to personal circumstances.

A fifth household mentioned the need for warmth to care for their aging mother:

I always turn the heating on when my parents come over, to make sure they're warm. There's only my partner's mum left now, but we always try and make sure she's warm because she's 90. So, she feels the cold as well. That's a ten out of ten on the list of importance. It's a high priority.

The theme on alleviating pain shows how those participants who have ongoing and serious health conditions, such as arthritis or cancer, have much more compelling and constant heating needs than may otherwise be the case. In some instances, this need to use heat to alleviate heat-related health conditions conflicts with other needs, for instance to reduce cost, cut waste or protect the environment. Though there may be a tension, the need to promote health is often perceived as the more important.

4.3. Fresh air: window opening

In contrast to heating for children or health, the theme of fresh air focuses on air quality (relating go health) and coolness (relating to comfort), in particular the need for fresh air and letting heat *out* of buildings or rooms.

For example, one household admitted during an interview that:

I open windows to cool down, that happens regularly. Upstairs, apart from when it was very, very cold we generally have bathroom [window] always open a little bit. It's always open, unless we're downstairs or out of the house. Obviously, we do this for condensation. Our bedroom window, we have two that are open out and then we've got the skylight one, and that's open. We do this pretty much all year round, yes. We need just a bit of fresh air, you know?

The example relates to condensation which could be about protecting the property from damage, or keeping it clean, or reducing risk of mold which relates to health.

Another household mentioned the need to segment their colder, fresh air room from others in the household:

I do tend to open my windows much. Sometimes I leave them wide open. I tend to sleep with my window open, but then I close my bedroom door when I have my window open, so it doesn't cool the girls' rooms down. The bathroom windows are always open. Although we

have an extractor fan, they're always open for showers and things. Then, I guess, that window will be open when cooking, like, loads of pots and things. Then, apart from that, I guess, yes, like, in the summer, windows and doors are always open, but it does not matter anyway because the heating's not on. In the winter, I tend to just have them either ajar or, like, once a week, just when I am airing the house out.

A third household stated the need to keep *particular* windows always open:

I have always left windows and doors open. I like some fresh air. I keep my bedroom windows permanently open, even in the winter, at least one. I also like to keep the bathroom windows permanently open, the kitchen window is often open, the backdoor is often open as well to get a good flow of air through the house. I do not want the house to feel stuffy or too warm.

A fourth household even stated that cold and fresh air were a central part of their sleeping habits:

Keeping the windows open is really important to me. I can't sleep when it's warm. I can only sleep when it's cold. For me, it's a nightmare having a warm bedroom.

A fifth remarked that this was a cultural practice reflecting the cultural heritage of their partner:

My wife tends to open the windows upstairs in the bedrooms, just to freshen the place up, as such. Even when it is cold she'll do that, as well, but I think that's a cultural type of thing to do. Normally in the nighttime. Earlier on, before I did the school run, all the windows upstairs were open, but then as soon as we went out the house we had to close the windows.

The theme of fresh air shows how some participants associated warm rooms with poor sleeping conditions and stuffiness, also using open windows as means of reducing condensation from cooking and bathing, and to remove unpleasant odors from cooking food and using toilets.

4.4. Personal care: the joys of a warm bathroom

The theme of personal care focuses particularly on the bathroom, especially how hot water and heat are used to assist with preening and cleansing.

One household noted in an interview that:

I turn the heating on in the bathroom because I enjoy a warm bathroom, I think that's it when you get out the shower in the morning you want the room to be warm, more important I find in the morning, so yes, because in the evening it's come on a little bit before I come home from work.

Another mentioned how the bathroom was a semi-sacred space where, unlike other rooms, the heat is always left on:

The bathroom is special, as that is where I always have the heat on. I just like to have it on all the time … Get up, the bathroom's warm and come down here and it's nice and warm. Unless the weather is really hot, the mornings are quite chilly. It is kind of being really extravagant but I am quite happy with it.

A third household stated that warm bathrooms were critical to stop their children from complaining, and a mechanism that facilitated more leisurely rates of dressing:

Keeping the bathroom perpetually warm is a family thing, isn't it? It's keeping the kids warm coming out from the bath or shower, because if they're not warm, they start moaning, start playing up and things like that. They'll start nagging you, 'I'm cold, I'm cold.' … So, it's thinking about things like that. I mean, it's almost like a luxury, in my opinion, to actually go into a bathroom which is warm, then have a shower or bath and then come out and not be freezing and not have to get dressed as quickly as you can.

A fourth household remarked that they *love* their warm bathroom:

It is great to actually walk into a warm bathroom and walk out of a nice shower, especially in the winter… I love walking into a warm bathroom and also getting out of a shower or a bath and the room's warm.

A fifth household agreed, and noted that the bathroom was in a special class of rooms in the house:

You know at a time when the rest of the house is not particularly warm, but you don't want to warm everything up, it is quite nice just to, sort of, give that extra boost to the bathroom. Obviously, you know, the bathroom is quite warm anyway because you've got, like, a heated towel rail in there, but it's nice to give it that extra boost. You know, just to give it, like, a half an hour boost before you go up there. It's a special room like that.

The theme on personal care shows the value that is put on for having a warm bathroom by the participants, who were in many cases willing to heat their bathrooms more than other rooms in the house.

4.5. Zoophilism: heating for pets and plants

The fifth theme highlights the perceived need to heat houses for pets or plants, something known as zoophilism, or the love of animals or non-human life.

One household stated during an interview that they needed to keep the house warm, even when traveling, for their four cats, and also that this was one of the most important aspects of heat for them:

I absolutely turn the heating on to keep my pets warm when I'm out of the house. That is true because even if, like, when I was on holidays, away for a few days and somebody came in to feed the cats, I would keep the heat on, because my four cats were here.

Another household agreed and noted:

We've got a cat, yes. So, we do put the heating on for them when we go away, or we always did.

A third household mentioned in a blog the need for heat for their dogs but also plants:

I am quite concerned that the heating isn't working properly as it's not getting up to the temperature programmed. I am on holiday but when my daughter went yesterday she said the house was freezing. I'm concerned as I've pets—two dogs—at home and I'm concerned about them. Same with my plants.

The theme of zoophilism shows how heating needs at home can go beyond the individual household members to including also those of their pets and/or plants.

4.6. Social signaling and caring: heating for houseguests

The theme of social signaling refers to the need of participants to heat homes for visitors and guests, and also to show others that their home is appropriately warm. In some situations, it is about "caring for others." Sometimes heating is about signaling because an occupant cares what others will think of them, but sometimes it's just about doing something for others (even if they never know). Some hosts pride themselves on making their home just perfect without anyone knowing or noticing all the things they've done – "oh it's no trouble".

One household put it this way:

In all honesty, we keep the house warm for guests, but in a weird way it's actually more for our comfort. We wouldn't let the house go

cold anyway and if people come across, it's the same as us. They've got to be comfortable same as me.

This reveals the duality to signaling and caring mentioned above: heating a home for visitors/guests and also to show others and signal. Another situated the need for a warm house in terms of what others might say about them:

> We want the house warm for visitors. Also, especially if my in-laws came, I'd make sure that the house was warm for them, because, again, I don't want them thinking, 'God, I went to that house and it was freezing!'

A third remarked about the social or cultural importance of maintaining a warm home for visitors, and projecting a "warming environment":

> Heating my house is an important signal for others, my first and foremost reason for having a warm home is to make sure not only that my children, the family, are warm, but importantly that any visitors that come, feel comfortable. There's nothing worse than feeling cold in the house. I don't want ever for visitors to come around and think, 'Oh, I don't want to go there because it's cold.' I want to project a warming environment. I want a home that is warm, comfortable, family friendly, and homely. That's what heat is for.

A fourth household discussed how a "warm home is a happier home," especially for guests, and needing them to feel "snug":

> My children are finishing school early today and although the house is acceptable for me to potter about in and come and go I know it doesn't feel snug. So as my son is bringing school mates home for the first time I've increased the heating in all the rooms he may be using so that they all feel comfortable and happy here. A warm home is a happier home.

Other households discussed the practical need to turn the hot water up when guests visit, so there is enough for everybody. As one household mentioned in their blog:

> I remember we had my partner's parents staying for a few days, so I have adjusted the temperature to keep them snug overnight so it does not drop below 17. We also altered the temperature in the morning for her shower, hopefully it will not be too hot, or too cold even. Nothing is worse than having only cold water available in the morning for everyone's baths or showers.

The social signaling theme shows how our participants valued heat not only for the sake of themselves, but also for others, in order to provide guests a comfortable experience when visiting their homes.

4.7. Structural fortification: heating for building protection

Our final seventh theme emphasizes heating not only for people, pets or plants, but for the building itself, as a way of fortifying or strengthening it.

One household said during their interview that heat was needed to prevent "damp," a colloquial term used for structural dampness, or the presence of moisture, water and condensation being present within a property that can lead to damage, noting that:

> We heat the house to prevent damp, every winter, we have a room that historically had a little bit of damp in the corner. I don't know whether that's been a benefit as well, and underlying benefit to the room, but we have heated the radiators upstairs throughout the winter period when it's been really, really cold, to protect the building structure.

Another household similarly indicated they heat to prevent damp, saying that:

> Our front room especially can get very cold without heat for an extended period, so just turning it off isn't really viable, especially as everyone has to go through this room to get into the house. With our bedroom too, we heat to avoid damp.

A third household said that:

> It's important to keep the building warm, you know? We haven't got damp and one of the reasons is presumably because we've got the heating on. Protecting your home against damp is a byproduct of having your heating on.

A fourth household discussed the need for heat to prevent frozen pipes as well as mitigating damp:

> I've never had damp here. It's not just the damp thing, it's the whole worry about frozen pipes and things like that. So, it is important to heat the house for the health of the house itself.

A fifth noted that:

> I sometimes turn my heating on just to protect my home against damp, especially in the very cold spell we had. Obviously we heat to stop the pipes freezing, as well.

Our final theme of structural fortification shows how heating a home does not only involve meeting the needs of its inhabitants, but also has material implications in terms of keeping damp at bay or stopping pipes from freezing.

5. Discussion: towards an energy phenomenology of smart heating controls and diverse practices

While we posit that the seven broad uses of heat described above are revealing and fascinating in their own right, they also do confirm the utility of the energy phenomenological framework. As Fig. 4 shows, one's *identity*—whether they see themselves as a parent, or a host, as healthy, or suffering from illness, for example, is a critical part of their heating needs and patterns. Heating dynamics are influenced by the multiplicity of their *preferences and needs*, for themselves and also others (including pets, plants, and even buildings). Embedded practices or *attachments* related to what is considered comfortable sleeping (e.g. with windows open), bathing (with a bathroom warm enough to dress slowly in), and even eating (keeping the door open to let fumes out) play their role. Shifts finally occur based on a mix of short- and long term *lifestyle changes* whether households are hosting visitors, raising and caring for young children, recovering from illness, managing long-term health conditions or merely aging (and thus becoming more sensitive to cold temperatures). We explore each of these four themes in detail in this section.

5.1. Individual identity

Individual identity can be defined as both the personality, beliefs, fears, and physical appearance of a person as well as the particular roles people assign to themselves such as a father, a doctor, an athlete, etc. [52]. Taken to mean how a heat user views themselves or expresses identity through their everyday doings in the context of our Living Lab, identity arises strongly from our evidence as a significant factor in heating dynamics. We situate individual identity as distinct from family identity, which is how a group of individuals view their overall life together [53]. Fathers and mothers seek to warm their home for their children, especially young children or "naughty" children seeking to dress downstairs outside of the bedroom. There was also evidence of parents wanting to emulate heating practices they had learnt in their own childhood to their children, like warming pajamas on a radiator. This implies how heating practices can be passed down generations—whether they are needed or particularly wanted as shown by the children complaining that their pajamas were too hot. As Hansen and Jacobsen [54] confirm in Denmark, such practices can be transmitted between generations, resulting in "like parent, like child."

One's identity can be further affected by illness, and suffering chronic conditions such as arthritis, or catastrophic conditions such as cancer,

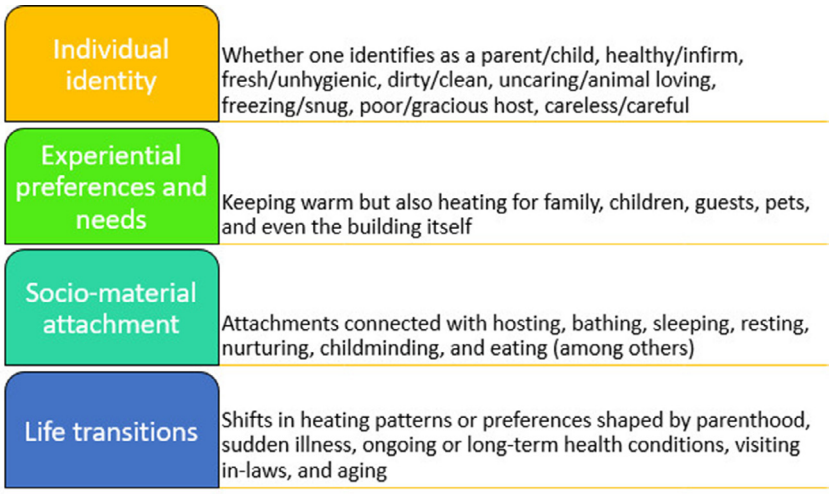

Fig. 4. Identity, needs, attachment and transition in the energy phenomenology of smart heating controls and practices. Source: Authors.

that can intersect with greater heating needs and greater vulnerability to feeling cold.

Those that identify as animal loving or caring for their plants, may heat their homes even when they are not physically present. Our results show that some participants wanted to come across as being gracious hosts with "snug" homes, so that those who visit will not think of them as living in a cold house.

Rationalizing heat consumption—undertaking it for purely instrumental ends—was particularly relevant for those who wanted to heat the building in their attempts at fighting damp and preventing freezing pipes.

5.2. Experiential preferences and needs

People use heat in certain ways to meet specific needs or preferences. The experiential preferences and needs for heat are complex, with a multitude of needs as well as different objectives for those needs. Heating uses can span across different compositions of energy phenomenology (e.g. identity, needs, attachment and transition) and we also see several fundamentally different logics to heating.

One household for example, endearingly, mentioned having to keep the house warm for an important birthday party for a cat, fusing together zoophilism and social signaling as well as caring for others' comfort:

> When people come over, we want to make sure the house is warm. Especially if there is something special going on, like it being the cat's birthday or something crazy like that. We just have a party for anything. Any excuse for a party. So when I am roasting a dinner on a Sunday or something, and then we had an excuse for a cake and stuff, people will come over. And some of our friends are old, or disabled, so we need to keep it always really warm for them.

In simpler terms: smart heating serves different needs. At a basic level, some preferences are intrinsic—heating within a household for personal comfort, for health, for fresh air, for cleanliness and preening, and for getting dressed. Some preferences are extrinsic, and for others, i.e. for other family members (especially children), visiting guests, pets (i.e. a spectacular cat birthday party for friends), plants, and even inanimate objects such as the wooden structures of a house or the perceived structural health and vitality of a room or a living space.

Additionally, heating is (oddly) not only about keeping warm. In some instances, it is about the lack of heat, about opening doors and windows to maintain freshness or clear the air. For many people, convenience (as conventionally understood) appears not to be a foundational value for heating by itself, but important when integrated with other values (such as health, care or comfort). For instance, we see parents with perceptions of heating as required for the wellbeing of their children being a core driver for keeping a home warm and dry, especially for those with respiratory diseases such as asthma. The fundamental logic here is one of nurturing or child welfare. We see those who need to alleviate pain use hot water or heat to relieve chronic pain. For people recovering from serious illness such as heart attacks or strokes, or cancer treatment, there is a pressing health reason for keeping a constant comfortable temperature at home. This is fundamentally about needs for health and vitality. Closely linked to health, the preference for fresh air sees perpetual window opening and is fundamentally about the preference for freshness, and for hygiene. Hygiene also links to personal care or preening which prioritizes preferences such as the joy of a warm bathroom and keeping clean by removing dust and dirt – this is fundamentally not only about hygiene but also about comfort.

Heating preferences and needs also go beyond heating for bodies, with zoophilism extending extrinsic heating preferences to animals and/or plants. The fundamental rationale is one of care beyond people, that also extends to building protection to fight damp or prevent freezing pipes. Social signaling plays a part as it is similarly about heating and caring for guests, about meeting cultural conventions of a warm and friendly home. The need here is partially one of cultural conformity.

5.3. Socio-material attachment

Preferences for heat do not exist in a vacuum; households become attached to particular ways of heating, which are conditioned by history and culture, and shaped by infrastructure. Groves et al. [55] refer to this as an "attachment to a practice." That is, the phenomenological patterns of heat are shaped by previous decisions and habits such as how homes were heated when people were growing up (intergenerational transmission of practices) as well as where they are located (availability of heating infrastructure). Henwood et al. [[11]: 6] reached a similar conclusion in their energy biographies work, when they noted that people "may form attachments to particular technologies or devices even if (or sometimes because) they are 'inconvenient'. In many cases, the value found in such attachments derives from how they foster experiences of connectedness or active physical, emotional and/or imaginative engagement with others and with the world."

We confirm this finding as well, showing that people develop strong attachments to particular smart heating practices, which may be less sustainable (e.g., keeping the bathroom always warm, keeping the heat always on for pets) or more sustainable (letting rooms reach natural/colder temperatures for sleeping, extending the life of building structures by mitigating damp). These attachments undoubtedly shape heating profiles, determine preferences and practices, and affect heating outcomes.

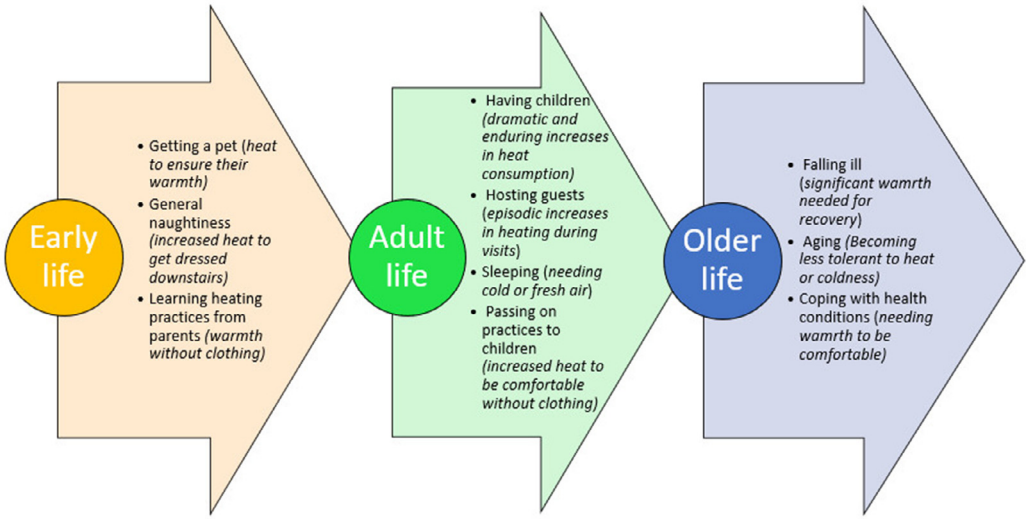

Fig. 5. Changes in smart heating practices or preferences across stages of early, adult, and older life.
Source: Authors.

5.4. *Lifestyle changes*

Our final finding is that our experiences of heat are transformed through life transitions or changes in lifestyles. Important phases that impact heating dynamics include getting a pet, having children, or suffering from a debilitating and lasting illness. Changes can be prompted by more minor events in life, too, like a change in office location changing where one lives, or a neighbor moving out so their home is no longer heated and an occupant needs to use more heat to make their home feel comfortable.

As Fig. 5 depicts, these may roughly group into early life, adult life, and older life. Early life would reflect things such as a child getting their first cat, or a cheeky child seeking to willingly behave in ways that consume excess heat. Adult life would involve permanent or more episodic changes in heat involving having children, hosting guests, or becoming dependent on fresh cold air for sleeping. Indeed, it is during this part of a lifestyle that parents could promote "wrap up warm" styles of heating vs. "I put the heating on to make sure my little ones don't feel the cold." Are parents heating (more) to protect a child, or heating (less) to deliver tough love? Older life could entail possibilities such as falling ill for an extended period, or growing merely more sensitive to changes in temperature through aging. These personal life transitions or phases not only better describe the temporality of heat, its inherent dynamism; they also have significant implications for policy, as they could be predicted and offer possible promising intervention points for better heat management.

6. Conclusion and policy implications

Rather than merely germinating from rational choices reduced to a process of calculation based on available information about costs and benefits, smart heating controls—an important tool for the decarbonisation of buildings, fossil energy, and electricity—reflect the phenomenological process of household heating. Smart heating controls and associated heating practices involve individual identities and senses of self; a multiplicity of preferences and even needs for heat; an attachment to particular infrastructures, historically shared practices, and routines; and transformations linked to personal life transitions or changes in lifestyle. Within this milieu, individuals are "ethnographically particular" and also simultaneously conduits for heating practices, members of a community of place and a subject of their own energy biography. Heating patterns, preferences, and practices consequently vary across time—changing across lifestyles, or when people move into new or old properties—and space—being shaped by the availability of heating technologies and also cultural issues such as gender, parental care, conventions for raising children, class and social signaling. Heating practices can be transmitted between generations, from parent to child, such as heating the house so warm one does not need to wear a jumper or even pajamas. The built heated environment has a mutual interaction with its social occupants that lead to a vexing variation of different needs and uses of heat.

One sobering implication from our findings about smart heating controls is that it does call into question people's knowledge and expectations about heat overall, as well as the research tools we use to often gage their knowledge or preferences, such as surveys or other stated preference techniques that presume heating attitudes or practices can be "known" beforehand. Instead, our results suggest that for occupants, heating preferences can be discovered through a process of learning, engagement and living, rather than existing as something innate or predetermined, or known in advance. People often do not know what heating services they want or value, they figure it out as they go, it becomes a process of their lived experience, and entrenched in their identity or energy biography. This highlights the utility of the energy phenomenology approach, and it suggests that building modelers, architects, and researchers rely more on *revealed* preferences rather than *stated* preferences. This means also examining heating preferences simultaneously across space (different rooms), time (living) and phenomenology (experience).

This raises a deeper query about heating knowledge, which we are unable to fully answer here: is it innate (within someone), created (by occupants or even researchers), or discovered over time (what we seem to find here)? It also suggests stark implications for policy: for if planners relied more on revealed, rather than stated heating preferences, they would build better buildings, taking into account how heat is used in different parts and rooms across the home, and draw more accurate conclusions. Put another way, findings for policy need to be grounded in more realistic household data allowing for diversity, and in some cases irrationality and unpredictability, of heating practices to be taken into consideration. These need to be then extrapolated outwards to ensure the humanizing elements of heat are not lost or (worse) impeded by policy changes. Our findings lastly suggest that the mental models people use to comprehend heat, and expectations about heat, are mediated by a confluence of material infrastructures, social routines, cultural conventions, and historical trends. They are recursive, processual, and co-created.

Furthermore, more concrete suggestions for heating or energy policy arise from our findings. The UK government implemented in 2019 a legally binding target of net zero for greenhouse gas emissions by 2050. In practical terms that means the urgent need to find ways to live carbon free [56,57], including driving cars and heating homes without emitting *any* carbon. Arguably, governments around the world are making far more progress on transport than they are on heating. It is intriguing to contrast the policy approaches in the two areas. With transport, policymakers are banning the sale of diesel and petrol cars. The automotive sector is responding by designing attractive low carbon vehicles for consumers [58]. In contrast, with domestic heating, policymakers are often introducing different measures to try to increase energy efficiency and drive the uptake of low carbon heating systems. These policies usually focus on minimizing cost. Carmakers have learnt what consumers want from vehicles and offer a range of vehicles to suit, including premium vehicles at very high prices that are leading the way (e.g. Tesla). The heating industry in contrast is responding to government policy by designing whatever components policies encourage. Perhaps the most profound implication of this paper is that it might be worth policymakers exploring whether they can apply the same approach that appears to be working for the automotive sector, to try to decarbonize the heat sector. If the heating industry was set a technology neutral target, as the automotive sector has been, then it might develop a range of low carbon heating solutions to meet the broad range of needs consumers seem to have for heat in their homes.

Suggestions for the future design of smart heating systems arise from our findings as well. As this paper shows, households use heating for so many reasons beyond getting thermally comfortable. Various studies have shown how much people value using heat to enhance health, enrich relationships and protect property [13]. Yet the focus for many domestic heating technologies is on achieving set point temperatures using energy efficiently. There are of course notable exceptions, including:

- the emergence of new technologies that offer to purify the air as well as help people get more comfortable (e.g., the Dyson purifier);
- the relatively recent return to grace of older technologies like wood burners and stoves (e.g., log-wood burners, AGA stoves);
- electric fires which shine light on water vapor to look like flames because they make people feel more comfortable (e.g., Glen Dimplex).

The fact that these innovations are currently sold as luxury products at premium prices demonstrates that there could be significant potential for smarter heating to meet a broader range of consumer needs—another similar tend to Tesla and the uptake of luxurious forms of electric mobility [59].

For these reasons, in terms of future research, we strongly believe, or at least hope, that the energy phenomenology approach can be expanded outward to look at other energy services and practices, including space cooling, mobility, and prosuming (to name a few). Moreover, our study has utilized original data from a Living Lab, but within this Lab there were limited number of rental properties and no homes in fuel poverty for example. We suggest that future research tests our findings in more varied building and tenancy types, and climatic conditions. We encourage research in the following two areas in particular: 1) the heating phenomenology of vulnerable consumers (e.g., along the lines of [60]), of how precariousness, power and equity intersect with the built environment to explore heat in more socially urgent contexts; and 2) in homes that utilize renewable heat, to examine the heating phenomenology of low or zero carbon heat.

Ultimately, energy research that does not account for the phenomenological aspects of smart heating controls, and how and why people participate in them, may never adequately comprehend why changes in heating occur, or why smart heating is adopted (or not). For heating itself can reflect or entrench motivations as diverse as raising children, caring for pets, preening oneself in the bathroom, or preserving a home's building value. Policy and research efforts that fail to appreciate these dynamics do so at their peril.

Conflict of Interest

We hereby confirm that none of the authors have any formal conflicts of interest related to the manuscript.

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